REPORT DOCUMENTATION PAGE

Form Approved OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
1992

3. REPORT TYPE AND DATES COVERED
Proceeding, 1992

4. TITLE AND SUBTITLE
Retrieval of Cirrus Radiative and Spatial Properties Using Independent Satellite Data Analysis Techniques

5. FUNDING NUMBERS
N/A

6. AUTHOR(S)
Robert P. d'Entremont, Donald P. Wylie, J. William Snow, Michael K. Griffin, and James T. Bunting

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Satellite Meteorology Branch
Geophysics Directorate
Phillips Laboratory
Hanscom AFB, MA 01731-5000

Space Science and Engineering Center
University of Wisconsin-Madison
Madison, Wisconsin 53706

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

SERDP
901 North Stuart St. Suite 303
Arlington, VA 22203

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
N/A

11. SUPPLEMENTARY NOTES
Presented at the Sixth Conference on Satellite Meteorology and Oceanography, American Meteorological Society, Atlanta, GA, pp. 17-20, 5-10 January 1992.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release: distribution is unlimited

12b. DISTRIBUTION CODE
A

13. ABSTRACT ***(Maximum 200 Words)***

Cirrus is one of the most poorly quantified clouds. As a part of International Satellite Cloud Project (ISCCP), intensive observations of cirrus clouds were taken in the autumn of 1986 over Wisconsin. During this First ISCCP Regional Experiment Cirrus Intensive Field Observation (FIRE Cirrus IFO), coordinated measurements from satellite, aircraft, and ground-based platforms were made of cirrus clouds.

This paper deals with the verification of cirrus cloud information, both spatial and radiative, obtained for a 1986 FIRE cloud scene using measurements from two independent sensors onboard the NOAA-9 polar orbiting satellite. In addition to the wide variability in properties common for other types of clouds, cirrus clouds have the added complexity of transmissivity values t that span the entire possible domain $0 \le t \le 1$. Thus, uncertainties exist in thin cirrus cloud amount, altitude, thickness, and optical properties as retrieved from satellite because the measured cirrus signal is affected additionally by an unknown radiation component from below.

14. SUBJECT TERMS
ISCCP, cirrus clouds, SERDP

15. NUMBER OF PAGES
4

16. PRICE CODE
N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclass	unclass	unclass	UL

1.7

RETRIEVAL OF CIRRUS RADIATIVE AND SPATIAL PROPERTIES USING INDEPENDENT SATELLITE DATA ANALYSIS TECHNIQUES

Robert P. d'Entremont [1], Donald P. Wylie [2],
J. William Snow [1], Michael K. Griffin [1], and James T. Bunting [1]

1 - Satellite Meteorology Branch
Geophysics Directorate, Phillips Laboratory
Hanscom AFB, Massachusetts 01731-5000

2 - Space Science and Engineering Center
University of Wisconsin - Madison
Madison, Wisconsin 53706

1. INTRODUCTION

The role of clouds in climate is receiving emphasis in the US Global Change Research Program. The current consensus among researchers is that clouds have a net cooling effect on the Earth's climate, but how much effect is still in question (Arking, 1991). Important factors include cloud fraction, altitude, and optical depth. The only continuous and truly global observations of clouds are provided by satellites; however, questions remain concerning what information can be retrieved and how representative it is of true cloud conditions. To this end, the International Satellite Cloud Climatology Project (ISCCP) is a worldwide effort to obtain accurate estimates of global cloud data from satellites for climate models (Rossow and Schiffer, 1991).

Cirrus is one of the most poorly quantified clouds. As a part of ISCCP, intensive observations of cirrus clouds were taken in the autumn of 1986 over Wisconsin. During this First ISCCP Regional Experiment Cirrus Intensive Field Observation (FIRE Cirrus IFO), coordinated measurements from satellite, aircraft, and ground-based platforms were made of cirrus clouds.

This paper deals with the verification of cirrus cloud information, both spatial and radiative, obtained for a 1986 FIRE cloud scene using measurements from two independent sensors onboard the NOAA-9 polar orbiting satellite. In addition to the wide variability in properties common for other types of clouds, cirrus clouds have the added complexity of transmissivity values t that span the entire possible domain $0 \leq t \leq 1$. Thus, uncertainties exist in thin cirrus cloud amount, altitude, thickness, and optical properties as retrieved from satellite because the measured cirrus signal is affected additionally by an unknown radiation component from below.

2. CIRRUS RETRIEVAL MODEL ATTRIBUTES

Multiple cirrus analysis models are useful for verifying independently derived cirrus characteristics within the same cloud scene. The results from two such models are compared in this study; the CO_2 Slicing technique and a multispectral Advanced Very High Resolution Radiometer (AVHRR) infrared cirrus analysis model developed by d'Entremont et al. (1990) called the AVHRR Infra-Red Cirrus model (AIRC). While the fundamental requirement to detect and analyze thin cirrus is the same for both models, the capabilities of the two models differ in numerous respects. Table 1 lists the important attributes of the HIRS CO_2 and AIRC cirrus retrieval models. The most important differences are the spectral bands and spatial resolutions of the satellite-detected radiances used by each model.

In recent years the CO_2 Slicing technique has been extensively applied to obtain cloud statistics on a global scale (Wylie, Menzel, and Woolf, 1991). The technique estimates cirrus altitude and the product of cloud fraction (N) and emissivity (ε), called "effective emissivity ($N\varepsilon$)" using radiances from the NOAA High-Resolution Infrared Radiation Sounder (HIRS) CO_2 spectral channels in the 13.4-14.2 μm range. It is capable of detecting transmissive cirrus clouds at upper tropospheric altitudes above levels where the CO_2 channels' weighting functions peak. At these HIRS CO_2 wavelengths the differential absorption of atmospheric radiation allows the CO_2 Slicing method to detect transmissive clouds. When a transmissive cloud is found, the HIRS Channel 8 (11.1 μm) IR window brightness temperature measurement T_8 is used along with an estimate of the surface skin temperature T_{sfc} to compute effective emissivity and cloud altitude. If the CO_2 channel radiances do not detect the presence of transmissive cloud, then an

Attribute	AIRC	CO_2 Slicing
Input Satellite Data:	AVHRR LAC/GAC IR Window Chs 3, 4, and 5	HIRS CO_2 Sounder Chs 4 - 7, And IR Window Ch 8
Analysis Resolution:	Nominal: LAC - 1 X 1 km^2 GAC - 4 X 4 km^2	Nominal: 25 X 25 km^2
Retrieved Parameters:	IR "Effective" Emissivities; Effective Altitude; Cirrus Fraction	IR Effective Emissivity; Effective Altitude

Table 1. Attributes of Cirrus Analysis Models

emissivity of 1.00 is assumed and T_8 is compared to the temperature profile to assign a blackbody cloud top pressure. Cloud climatologies produced using the CO_2 slicing method have been extensive, focusing on the geographical, seasonal, and diurnal changes of cloud cover (Wylie and Menzel, 1989; Menzel, Wylie, and Strabala, 1991; Wylie, Menzel, and Woolf, 1991). Through these studies the first-order radiative characteristics of transmissive cirrus clouds are now better ascertained on a global scale.

CO_2 Slicing cloud analyses have been compared with lidar measurements and NWS ground-based cloud reports (Wylie and Menzel, 1989). Comparisons with other satellite techniques, however, have not yet been made. This paper presents the early results of the first such comparison with the AIRC cirrus retrieval model. AIRC generates cirrus emissivities, transmissivities, and optical depths, along with effective cirrus layer altitude. AIRC determines these cloud properties using the differences among AVHRR 3.7, 10.7, and 11.8 μm IR window brightness temperature measurements. The model is based on simple radiative transfer principles that account for both the semi-transparent nature of cirrus clouds and the attenuative effects of atmospheric water vapor in the AVHRR thermal window regions.

Resolution differs considerably between the two models. For the HIRS data, this FOV is large: nominally 490 km^2, corresponding to a 25 km diameter. It is expected that most HIRS FOVs are not uniformly cloud covered and contain large variations in cloud density. This has the effect of not allowing an analysis of the HIRS-derived cirrus emissivity itself; it is intrinsically tied to cirrus cloud fraction. Like the CO_2 technique, the AIRC model can only resolve the "effective" emissivity. However, AIRC is applied to Local Area Coverage (LAC) AVHRR data with a nominal FOV of 0.8 km^2, corresponding to a 1 km diameter. Compared to HIRS pixels the AVHRR LAC pixels have less variation in cirrus cloud density and, except near cirrus edges, are more often either entirely clear or entirely cloudy. This dichotomous state of the AIRC cloud amount (N = 0 or 1) allows direct determination of cirrus emissivity.

3. DATA ANALYSIS

Nighttime AVHRR Local Area Coverage (LAC) and coincident HIRS CO_2 sounder radiance data valid at 0930 UTC on 28 October 1986 were collocated on a local Cartesian coordinate grid centered on Wisconsin. Imagery from the AVHRR 3.7 and 11.8μm thermal channels (3 and 5) is presented in Figures 1a and 1b, respectively. These images show widespread cirrus flowing southeastward into Wisconsin, just ahead of an upper-level ridge axis. Cirrus are also found over southeastern Wisconsin near Madison. Note the seemingly more extensive detection of cirrus in the

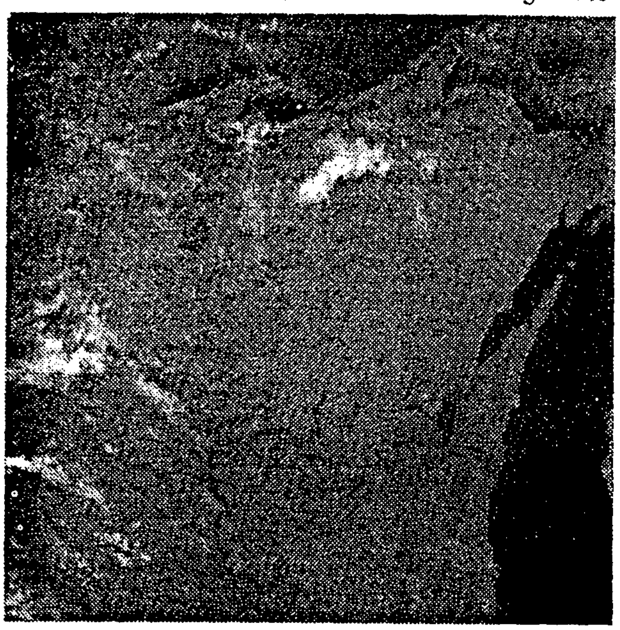

Figure 1a. AVHRR 3.7 μm Image for the 0930 UTC 28 October 1986 FIRE IFO

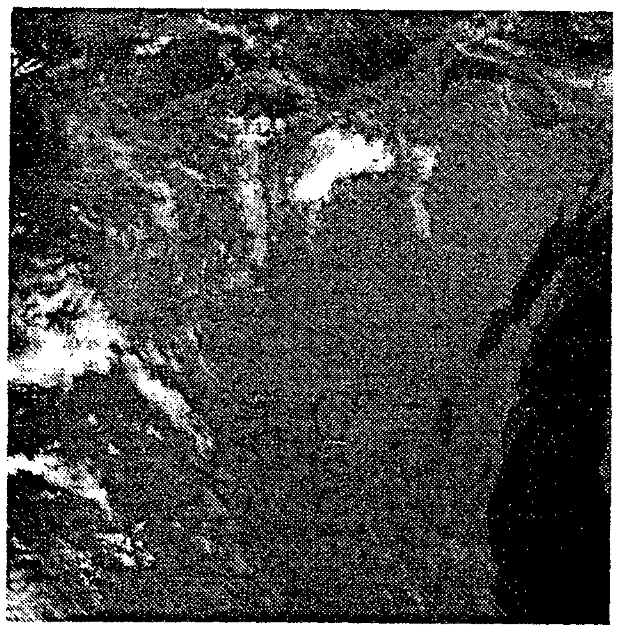

Figure 1b. AVHRR 11.8 μm Image for the 0930 UTC 28 October 1986 FIRE IFO

11.8 μm image, and the apparent lack of cirrus in the corresponding regions of the 3.7 μm image, especially thin cirrus. This distinctive difference between observed mid-wave and long-wave IR brightness temperatures enables AIRC to detect and subsequently analyze thin cirrus.

All AVHRR pixels in Figure 1 were first checked for cirrus presence using the detection algorithm:

Cirrus: $T_3 - T_4 > 0.5\,K$, (1a)

Thin Cirrus: $T_4 - T_5 > 0.6\,K$ AND $T_4 < 273\,K$, (1b)

and *"Obvious" Ci, Cs:*

$T_4 < 255\,K$, (1c)

where T_3, T_4, and T_5 are the AVHRR 3.7, 10.7, and 11.8 μm brightness temperatures, respectively. This algorithm is adapted from the AVHRR cloud detection scheme presented by Saunders and Kriebel (1988). If any test is satisfied, cirrus presence is established; Figure 2 shows the results of this cirrus screening. Inspection of animated sequences of GOES IR window channel images verified these cirrus locations based on their movement, and confirmed the lack of cirrus in central Wisconsin. Once identified as cirrus, each pixel triplet of AVHRR brightness temperatures (T_3, T_4, T_5) is further analyzed using the AIRC model for emissivity and effective cloud layer altitude.

Figure 3 contains the HIRS grid for the image shown in Figure 1. A total of 153 HIRS pixels within the Wisconsin area were analyzed by Wylie and Menzel for effective cirrus emissivity $N\varepsilon_{CO2}$ and effective cirrus altitude z_{CO2} using the CO_2 Slicing technique. Coincident with the HIRS grid are 139,649 AVHRR LAC pixels, each with an AIRC analysis of cirrus emissivity ε_{AIRC} (N is assumed 1 for the 1-km LAC resolution) and effective layer altitude z_{AIRC}.

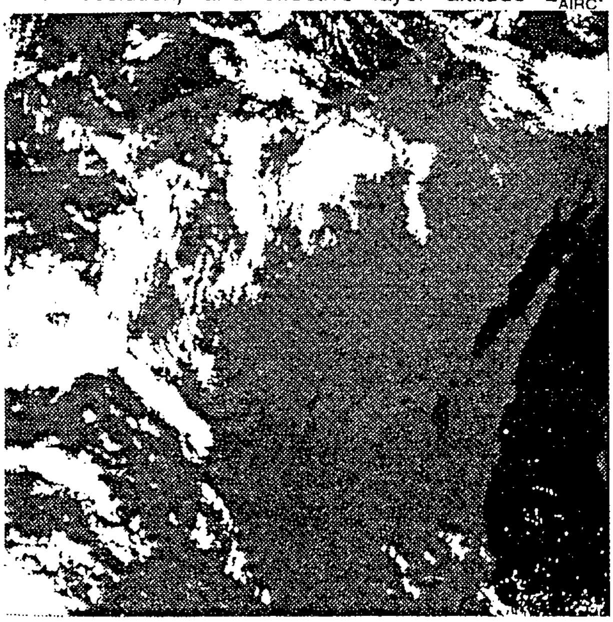

Figure 2. Cirrus Detection Results for the Image Scene in Figure 1. Bright Pixels Denote Cirrus

Having compiled the results of the CO_2 and AIRC analyses, a comparison was then performed of the independently retrieved effective cloud altitudes and emissivities.

4. COMPARISONS

For each HIRS FOV, a cirrus cloud fraction N is obtained from the AVHRR data using the cirrus detection algorithm specified by Eq. (1). This fraction is used to separate the CO_2 cirrus emissivity ε_{CO2} from the effective emissivity. The resultant 11.1 μm emissivity ε_{CO2} can be compared to the average AIRC 10.7 μm emissivity ε_{AIRC} of the cirrus-filled pixels over the same area. The important point to note here is that the AIRC analysis allows for removal of the cloud fraction dependence of the CO_2 effective emissivity $N\varepsilon_{CO2}$.

Figure 4 contains a scatter plot of the CO_2 effective emissivity $N\varepsilon_{CO2}$ vs. the AIRC cirrus cloud fraction N. Points above the line $N\varepsilon_{CO2} = N$ are spurious because ε is constrained to be ≤ 1.0, and thus $N\varepsilon \leq N$. The large majority of $N\varepsilon_{CO2}$ values above the $N\varepsilon = N$ line represent CO_2 opaque cloud reports ($N\varepsilon_{CO2} = 1$) in areas where AIRC found little or no cirrus and where the CO_2 radiances detect no *transmissive* cloud. These opaque clouds were reported due to an overestimate of T_{sfc} , causing T_8 to be flagged as sufficiently colder than the background and hence indicative of opaque lower cloud. Other spurious CO_2 points are likely due to upper tropospheric water vapor in amounts that differ from those the CO_2 Slicing algorithm accounted for.

In Table 2 the CO_2 emissivities ε_{CO2} are compared to the average of the AIRC emissivities ε_{AIRC} of the cirrus-filled pixels within corresponding HIRS FOVs. Spurious CO_2 opaque cloud reports were eliminated

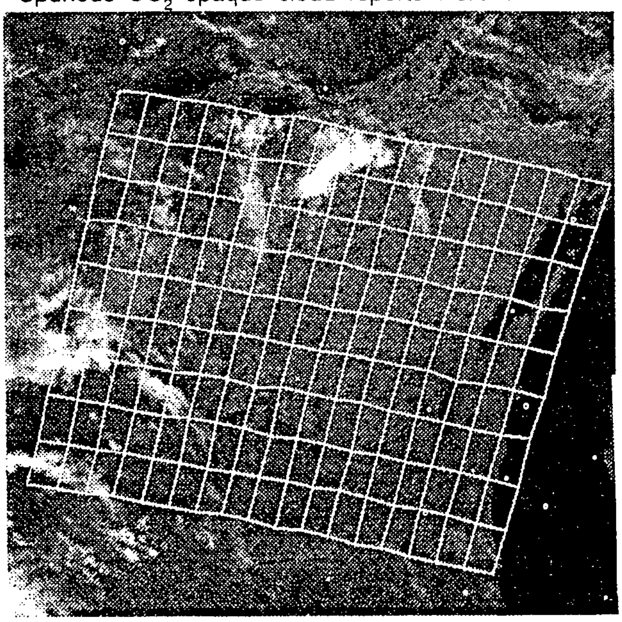

Figure 3. AVHRR 10.7 μm Image for the Analysis Area of Figure 1, With the HIRS Grid Overlay

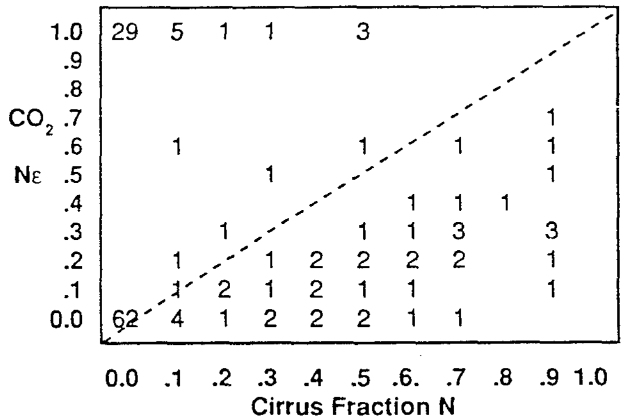

Figure 4. Scatter Plot of CO_2 Effective Emissivity $N\varepsilon_{CO2}$ vs. AIRC Cirrus Fraction N. 62 HIRS FOVs Were Determined "Clear" by Both Techniques

Emis-sivity	Mean	Std. Dev'n.	Correlation Coefficient *with Other ε Value*	Correlation Coefficient *with Cloud Fraction N*
ε_{CO2}	0.46	0.18	0.90	-0.14
ε_{AIRC}	0.44	0.13	"	0.46

Altitude	Mean *(km)*	Std. Dev'n. *(km)*	Correlation Coefficient *with Other z Value*	Correlation Coefficient *with Cloud Fraction N*
z_{CO2}	7.2	1.9	0.94	0.06
z_{AIRC}	7.2	1.0	"	0.16

Table 2. Statistics of Retrieved Cirrus Properties

from this analysis by restricting cloud fraction to be $N \geq 0.1$ (10%), and emissivity $0.1 \leq \varepsilon \leq 1$. The emissivity constraint is invoked because noisy HIRS and/or AVHRR radiance measurements can be confused with very thin cirrus, thus affecting the ability of either CO_2 Slicing or AIRC to detect and analyze such clouds. The correlation coefficient is 0.90 between the two independently derived IR-window cirrus emissivities. Overall, the CO_2 and AIRC models calculate average cirrus emissivities of 0.46 and 0.44, respectively.

Also listed in Table 2 are the comparisons between the CO_2 effective cirrus altitudes and the corresponding average AIRC altitudes. These values agree well, with a correlation of 0.94. In addition, the average effective altitude values Z_{CO2} and Z_{AIRC} for the HIRS grid are equal at 7.2 km. The range of retrieved cirrus altitudes analyzed by both the CO_2 and AIRC models agrees well with coincident surface-based cirrus lidar measurements reported by Sassen et al. (1990).

Retrieved emissivity and cloud altitude were also compared with cloud fraction. Table 2 shows the poor correlations between ε and N, and between z and N. These indicate a lack of dependence of retrieved cirrus emissivity on fraction, and a lack of dependence of retrieved altitude on fraction; such independence in both cases is physically reasonable.

5. SUMMARY AND CLOSING REMARKS

Radiative and spatial properties obtained by the CO_2 Slicing and AIRC models compare well for the cirrus clouds observed during the 0930 UTC NOAA overpass on 28 October 1986. The mean cirrus emissivities and altitudes retrieved by the CO_2 Slicing and AIRC models agree well with each other; 0.46 : 0.44 and 7.2 : 7.2 km, respectively, with somewhat greater variance evident in the CO_2 values.

For other more dense cirrus cloud conditions, especially those of extensive precipitating systems where N is large, CO_2 Slicing results (Wylie and Menzel, 1989) suggest that emissivity and fraction may not be totally independent. Such cloud conditions will be included in future studies. Also, the relationship between cirrus emissivity and altitude was investigated for the 28 October scene and no significant conclusion could be reached.

What is indicated by the analysis of this transmissive cirrus scene is that neither cirrus emissivity nor altitude is dependent on cirrus fraction. The consistent findings for both the CO_2 Slicing and AIRC models suggest that representative cirrus cloud properties are being retrieved.

BIBLIOGRAPHY

Arking, Albert, 1991: **The Radiative Effects of Clouds and Their Impact on Climate.** *Bull. Amer. Meteor. Soc.*, 72, 2-20.

d'Entremont, Robert P., Michael K. Griffin, and James T. Bunting, 1990: **Retrieval of Cirrus Radiative Properties and Altitudes Using Multichannel Infrared Data.** Proceedings, *Fifth Conference on Satellite Meteorology and Oceanography*, Amer. Meteor. Soc., 3-7 September 1990, London, England, 4-9.

Menzel, W. P., D. P. Wylie, and K. I. Strabala, 1991: **Seasonal and Diurnal Changes in Cirrus Clouds as Seen in Four Years of Observations with the VAS.** *Journ. Appl. Meteor.*, in press.

Rossow, William B., and Robert A. Schiffer, 1991: **ISCCP Cloud Data Products.** *Bull. Amer. Meteor. Soc.*, 72, 2-20.

Saunders, R. W., and K. T. Kriebel, 1988: **An Improved Method for Detecting Clear Sky and Cloudy Radiances from AVHRR Data.** *Int. Journ. Remote Sensing*, 9, 123-150.

Sassen, K., C. J. Grund, J. D. Spinhirne, M. M. Hardesty, and J. M. Alvarez, 1990: **The 27-28 October 1986 FIRE IFO Cirrus Case Study: A Five Lidar Overview of Cloud Structure and Evolution.** *Mon. Wea. Rev.*, 118, 2288-2311.

Wylie, Donald P., and W. P. Menzel, 1989: **Two Years of Cloud Cover Statistics Using VAS.** *Journ. of Clim.*, 2, 380-392.

Wylie, Donald P., W. P. Menzel, and H. M. Woolf, 1991: **Two Years of Global Cirrus Cloud Statistics Using HIRS.** Submitted to *Journ. of Clim.*